

CHAPTER 10

STATUS OF RESEARCH ON GEOLOGICAL DISPOSAL FOR HIGH LEVEL RADIOACTIVE WASTE IN FRANCE

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10.1 INTRODUCTION

Research programs in the field of high-level, long-lived radioactive waste management are defined and regulated by Law 91-1381 of December 30, 1991 (“the Waste Act”) and its implementing decrees, particularly Decree 92-1391 of December 30, 1992 pertaining to Andra and Decree 93-940 of July 16, 1993 on underground laboratories.

The Waste Act relative to research on radioactive waste management mandates three research programs on high-level and long-lived waste management:

- separation and transmutation of long-lived radioactive elements;
- solidification processes and long-term surface storage; and
- examination of options for retrievable and non-retrievable disposal in deep geologic formations, particularly through the construction of underground laboratories.

The first two programs are relegated to the French Atomic Energy Commission (CEA) and will be conducted in the latter’s laboratories. The Act confers responsibility for the third research program on Andra. In this capacity, Andra is charged with conducting a program of research and testing to examine the potential for construction of a retrievable or non-retrievable repository in deep geologic formations. Andra is also called on to participate in the other two research programs in association with the CEA.

Article 13 of the Waste Act charges Andra with long-term management of radioactive waste and “to partic-

pate in defining and conducting research and development programs on long-term radioactive waste management, in association with the French Atomic Energy Commission in particular. “

Annual progress reports on the three research programs are required (Article 4), as is an overall assessment report, “no later than 15 years after the promulgation of this law, accompanied by proposed legislation authorizing the creation of a repository for long-lived radioactive waste, as appropriate and establishing the conditions for essential and seats relating to this repository.”

These reports, to be prepared by the National Assessment Commission, are to be submitted by the government to Parliament, which refers them to the Parliamentary Office of Science and Technology Assessment. All reports will be made public.

The decree of December 30, 1992 relative to Andra additionally stipulates that the latter shall provide the following to its oversight ministries:

- an annual report on work performed to date or to be performed in the underground laboratories to determine the suitability of deep geologic formations for radioactive waste disposal; and
- a summary report on all findings no later than December 31, 2005, accompanied as appropriate by a design for an underground repository for high-level and long-lived radioactive waste.

This Technical Activity Report by Andra reviews studies performed to date and serves as a baseline for Andra research programs to be conducted over the coming

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years.

10.2 WHAT IS A DEEP GEOLOGIC REPOSITORY?

The purpose of geologic disposal is to contain radioactivity with a system of devices and measures that prevents radioactive materials transport to the biosphere, or at least limits it to a specified level.

Containment is based on the concept that a series of natural and artificial barriers can be placed between the source term, i.e., the waste itself, and the biosphere, listed below:

- the waste package (waste, solidification material, container and possibly overpack);
- the engineered barrier (repository structures and backfill material around the waste packages); and
- the geologic barrier (natural geologic media and access closure system).

The geologic medium plays a dual role in this scheme of things. It provides protection with respect to the source term and it protects the biosphere:

- by protecting the artificial barriers from human intrusion and the effects of weather;
- by providing a physical and chemical environment for the artificial barriers that is stable over long periods of geologic time; and
- by helping to retard and restrict radionuclide transport to the biosphere (retention, dilution before reaching the biosphere).

The three barriers in the containment system reinforce each other, with the geologic barrier playing a critical role in long-term containment. The overall integrity of the three-barrier system must be demonstrated.

Reference conditions for the multi-barrier system must be taken into consideration in two areas:

- the waste, expressed in terms of radioactive content, physical characteristics and solidification materials; and
- the geologic medium, represented by the formation and its surrounding geologic environment.

10.2.1 Waste

Generators have been generating and storing long-lived waste for several decades pending the availability of a

geologic repository. Most of this waste has already been solidified in a variety of materials in accordance with regulatory requirements: glass for fission products from reprocessing, and concrete or bitumen for dry active waste. Although Andra played only a small part in the preliminary selection of materials for this type of waste in the past, henceforth it will have a larger role, as spelled out in Article 13 of the law- “Andra is charged with defining, in accordance with safety regulations, radioactive waste solidification and disposal specifications.” Andra could, therefore, require the use of additional solidification materials, for example, even for waste that has already been solidified waste, or could change the cooling requirements for exothermic waste.

For purposes of long-term management, radioactive waste is differentiated by type, by activity level and by the half-life of the contaminating radionuclides it contains, based on the duration of their potential hazardousness.

Low- and medium-level, short-lived waste, called Category A waste, contains primarily beta- and gamma-emitting radioelements whose radioactive half-lives are approximately thirty years or less (such as cesium 137, cobalt 60, strontium 90, etc.). This waste, generated by routine nuclear facility operations, represents approximately 90% of the total volume of radioactive waste generated annually in France, but accounts for only 1% of its total activity. The radioactivity of this type of waste decays to natural levels in less than 300 years due to the relatively rapid decay rate of the radionuclides it contains, and it may, therefore, be suitable for near-surface monitored disposal during this time frame.

The other type of waste, which is long-lived waste and high-level waste, is divided into two categories, each of which includes long-lived waste:

- low- and medium-level Category B waste contains significant amounts of long-lived radionuclides, especially alpha-emitting transuranics;
- Category C waste contains high concentrations of both short- or medium-lived fission products and long-lived, alpha emitting transuranics.

Category C waste is highly radioactive and heat-emitting in the beginning, primarily because of its fission product contents, but this quickly declines due to the rapid decay rate of these short-lived elements. In the end, Category C waste will contain mostly long-lived elements, and represents the same types of hazards asso-

ciated with Category B waste. For the most part, Categories B and C waste come from spent power reactor fuel reprocessing and from civilian and defense research and production sites of the CEA. Category B waste will also be generated during nuclear facility dismantling and must be included in waste volume estimates for disposal.

The waste volumes to be generated in the coming decades are not yet finalized due to several uncertainties, particularly:

- the amount of fuel to be used in power generation, fuel burnups, and the back-end option selected (reprocessing or direct disposal);
- potential technical advances in reprocessing, particularly in the types and volumes of waste generated; and
- method selected to solidify existing waste,

Taking a simplistic scenario — light water fuel reprocessing of 1100 metric tons of initial uranium metal per year at a burnup of 33,000 MWd/t beginning in the year 2000 — the total volume of solidified waste through the year 2020 can be estimated at 100,000 m³ for Category B waste and 6400 m³ for Category C waste.

Data from tests conducted as part of the other two research programs mandated by law could result in major technical shifts in solidification processes affecting the types and volumes of waste generated by reprocessing in addition to their solidification. Conversely, as data becomes available at the underground laboratory sites, Andra may identify new priorities in the other two research programs. For example, a hierarchy of radionuclides may be established in light of the retention properties of the multi-barrier system, which could establish separation and transmutation priorities for certain radionuclides. Or, Andra may develop preliminary specifications for solidification materials based on disposal conditions in deep geologic formations.

All aspects of the final waste packages must be carefully characterized to facilitate geologic repository design. Characterization must not be limited to waste volumes or to the physical, chemical and radioactive characteristics of waste packages that have been or will be fabricated; they should also include long-term behavior, failure probabilities, and their interaction with other barriers. In the case of exothermic waste, duration of storage is an essential parameter for repository design insofar as it is a factor in the waste's temperature; Andra's calcu-

lations must therefore include the date that the spent fuel that produced the exothermic waste was discharged from the reactor.

Studies of the long-term behavior of waste packages will make it possible to assess containment capacity — and possibly to find ways of improving containment — and to make sure that the waste packages are compatible with the repository concept (receiving capacity, engineered barriers, handling, retrievability, etc.). This will result in waste package specifications that integrate both safety-related requirements and mechanical and physical requirements for waste package handling and disposal.

10.2.2 Geologic Barrier

Why dispose of radioactive waste in a deep geologic medium?

Surface disposal was rejected because the service life of any repository structures that could be built is much shorter than the half-lives of long-lived radionuclides. Moreover, it would merely postpone the problems of repository monitoring and maintenance to the future, with all the risks that that implies in the deliberately conservative scenario in which future civilizations are presumed to have neither the material means nor the technical capability to manage these problems.

Since the goal is to contain radionuclides for long periods of time, a medium with suitable radionuclide containment characteristics that evolves slowly is sought. Deep geologic formations may meet both of these criteria. There are vast areas of deep rock suitable for containing radioactive products for long periods of time.

At first glance, the low permeability and retention capacity of some of these rocks make them suitable for containing radioactive products. Enormous areas are available at depths of 200 to 1000 meters, a range that provides enough protection from surface intrusions yet does not compromise the technical feasibility of repository construction.

These available areas thus constitute physical barriers as much for the radioactive waste as for intrusions. They are also chemical barriers: water seeping through them is “buffered,” acquiring geochemical properties that usually are not very corrosive through interaction with the rocks. This phenomenon is what explains how uranium deposits could subsist for hundreds of millions of

years, for example. It also explains why the fossil reactors discovered in the Oklo uranium deposit in Gabon are an extraordinary illustration of the influence of the geologic medium in the repository scenario; fission products produced during “operation” of these natural reactors have remained trapped in place, contained and protected for nearly 2 billion years in an envelope of clay.

In addition, inasmuch as the excavated rock volume for a geologic repository will be a small percentage of the host rock volume (around 1%), the repository should not significantly modify the overall containment capabilities of the host rock, especially since the volume of waste to be disposed of will be even lower (around 1/10%).

Geologic evolution is slow enough to ensure containment integrity for the time necessary for the waste to undergo radioactive decay, as long as certain areas are avoided, such as those with recent volcanic activity or strong tectonic activity. Potential geologic events are limited to those that are possible in the geodynamic context of the area under considerations for example, the creation of a mountain chain during the time scales considered (around one hundred thousand years) is not plausible in a stable area such as the Parisian Basin.

To illustrate the slowness of geologic phenomena, one could also take the example of an area with a great deal of tectonic activity, such as the Messine and Calabre regions, which have risen by 1,500 to 2,000 meters in 5 million years at a geologically rapid average rate of 0.4 mm/yr.. For a stable area such as the Parisian Basin, the average estimated rates are 20 times lower, discounting the appearance of significant new discontinuities (fault fractures, etc.) in the reference time scale.

In recognizing the potential for disposal in deep geologic formations, can one therefore consider that all geologic media are valid? A consensus was quickly reached among international experts on three suitable media: granite, salt and clay. In France, the Second Castaing Commission (1984) had this to say about rejecting certain formations: *“A number of formations, known to be permeable, were rejected outright (sand, sandstone, limestone, basalt, etc.)”*. However, the Commission indicated its support for an extension of the initial selection list: *“In the first phase, three types of formations were selected at the European level -granite, salt and clay - perhaps without adequately emphasizing the variety of rocks that enter into these categories. The group considers that the list of rocks resulting from clay evolution*

(such as shale) or even their more highly metamorphosed forms (schist and some gneiss), which are widespread rocks, should not be rejected outright.”

Nonetheless, the fundamental role of the site itself was not forgotten in this expanded list: *“It is both a series of diverse formations and the interfaces between them that make a site attractive; the same formation at another site could be determined to be completely unsuitable.”* The Commission came to this conclusion: *“Potential variation in the properties of the formations, ranked by category, are so great that research must focus on specific rocks and sites as soon as preliminary screening is completed.”*

However, even the cited media have different theoretical advantages and disadvantages for disposal. In addition, one medium may be more suitable than another for exothermic waste disposal. Lastly, the geologic barrier will have to be reestablished by backfilling and closing the access shaft after the repository has been constructed, and the method of doing this differs for different media.

10.2.3 Engineered Barrier

Engineered structures and backfill material for the disposal pits and the surrounding galleries separate the waste packages from the geologic medium and constitute an additional barrier which, like the natural medium, plays a dual role:

- it protects the waste packages by minimizing water contact or by creating a chemical environment that is conducive to the long-term integrity of the packages; and
- it retains any radionuclides that may have been released from the waste packages.

The design of the engineered barrier should therefore take the geologic medium and the initial radioactive content of the waste into account, in addition to the exothermic properties of certain waste packages. This applies to C waste, unless the length of its storage is to be extended, which would lead to treating C waste separately from B waste.

10.2.4 International Consensus

International organizations agree that geologic disposal is the reference solution for waste management. Other possibilities for long-lived waste management were considered, but have been rejected. Sending waste into

orbit in space has been rejected as it is technically infeasible at the present time, given the volumes involved and reliability requirements. Waste burial in the earth's crust in the subduction zones of continental plates or in volcanos is not very realistic. Dilution by submersion in the sea is prohibited for long-lived radioelements by international regulations due to the risk of their return to members of the public. Burial in an ice cap was also considered; the heat of the C waste would serve melt the ice beneath each waste package, allowing it to gradually penetrate the center of the ice cap under its own weight, but implementation of this "solution" not only raises technical challenges, it also had the drawback of targeting areas that are increasingly being protected from industrial use.

France has participated in in-depth research, and an international test program has been conducted on waste burial in ocean bed sediments. Only simulated waste packages without any radioactive products were used during the program. On a technical level, and given the present state of the art, sub-oceanic burial is attractive from a safety point of view, but international legal considerations block its implementation.

Performance objectives established by the French regulatory authorities have been derived from recommendations of the International Commission on Radiological Protection (ICRP), an independent organization that analyzes the health effects of radiation exposure and develops recommendations for measures to be taken for protection from peaceful uses of artificial radioactivity. ICRP uses medical and epidemiological statistics and operating experience from a century of worldwide use of radioactivity.

Natural radioactivity comes from a certain number of radioactive isotopes that exist in nature. Natural radioactivity, and therefore exposure, varies significantly from one location on the earth to another; it varies considerably in France. Generally, the maximum allowable exposures to artificial radiation for members of the public must be less than the average exposure to natural radiation. In this very conservative approach, it is further assumed that an individual may be exposed to several different sources, and therefore, only a fraction of the allowable exposure may come from each source. The only exception to this rule is for radiation exposure for medical purposes, such as x-rays and radiation therapy, which may be much greater because the health benefits may be much higher than the related risks. ICRP recommendations are incorporated into the regulations of the International Atomic Energy Agency (IAEA) as

well as into French regulations.

International organizations have been engaged in research on geologic waste disposal for some time. This was set forth in the December 14, 1990 report on high-level nuclear waste management by the Parliamentary Office on Science and Technology Assessment and is summarized below.

10.3 CHARACTERIZATION OF GEOLOGIC MEDIA

In the preceding section, deep geologic disposal is recognized as a potential solution for long-lived and high-level waste. To go one step further, specific selection criteria must be identified for the characteristics of a suitable geologic medium and site in terms of the specific use for which it is intended.

A major phase in the deep repository program involves the definition of: selection criteria, criteria ranking, determination of objectives to be achieved for each criterion, and identification of the means of verifying that the objectives are achieved in a geologic medium selected to host a geologic repository. Considerable work has already been performed in these areas in France, culminating in the June 1991 issuance of Fundamental Safety Rule (FSR) III.2.f by the Ministry of Industry's Division of Nuclear Facility Safety, whose subject matter is described as follows: "Definition of objectives to be achieved during the design and construction phase of the deep geologic repository for radioactive waste to ensure safety after the end of the repository operating period."

FSR III.2.f is the culmination of deliberations and recommendations of several advisory groups that have been working since 1983 to develop a safety-related approach to radioactive waste repositories in deep geologic formations. These include:

- working group on research and development in the field of radioactive waste management, chaired by Professor Castaing;
- working group on technical selection criteria for a geologic disposal site for radioactive waste, chaired by Professor Goguel; and
- working group on scenarios to be used in safety analysis of a geologic repository.

In addition, FSR III.2.f takes the recommendations of cognizant international organizations into account, including those of the ICRP, IAEA, and OECD/NEA.

Two essential criteria are highlighted in the FSR: site stability and site hydrogeology. These are followed by important criteria, such as the mechanical and thermal characteristics of the medium, which determine the feasibility of repository construction, operation and closure-, and the geochemical characteristics of the media that could alter man-made barriers and determine radionuclide retention.

A minimum depth must be maintained to prevent the containment performance of the geologic barrier from being affected significantly by erosion (especially after glaciation), by a seismic event, or by the consequences of “direct or indirect human intrusion (drilling, milling, wells, surface or subsurface construction).” This last criteria translates into the need for geologic formations with suitable characteristics (mechanical characteristics, hydrogeology, etc.) in terms of repository safety but which also must be at sufficient depth. Lastly, there is an obvious advantage of using areas without natural resources that might attract mining activities at a later date.

10.3.1 FSR 111.2.f Criteria

The principal characteristics required by FSR 111.2.f for a disposal site for waste containing long-lived and high-level radionuclides are summarized in the following paragraphs.

Stability

“Site stability should be such that any modification to reference conditions by geologic occurrences (glaciation, seismicity, neo-tectonic shifts) must be acceptable from a repository safety perspective. In particular, stability must be demonstrated for a period of at least 10,000 years, which encompasses limited and predictable evolution. For each selected site and based on current conditions, these occurrences are to be assessed in qualitative and quantitative terms for the recent past (historical) and especially for the more distant past (Quaternary and possibly end of the Tertiary) so that the parameters characterizing these factors as well as their variations can be quantified and their influence determined. To accomplish this, it will generally be necessary to investigate the regional geologic environment of each site.”

Hydrogeology

“The hydrogeology of the site must be characterized by

very low permeability in the host formation and a low hydraulic gradient. Moreover, preference will be given to a low regional hydraulic gradient in the formations surrounding the host formation. Hydrogeologic measurements are to be performed in a much larger area than the repository site so as to construct flow models that factor in flows from the source to the discharge areas. The intensity and direction of underground flows can be simulated using these regional data. Discontinuities or heterogeneities which could significantly lessen the efficiency of the geologic barrier due to their type and geometry must be taken into account, and must be mapped and characterized with the greatest care so as to avoid them at the site, if necessary.”

The FSR also specifies the following four criteria as being important for site assessment.

Mechanical and Thermal Characteristics

“Repository feasibility is conditioned on [mechanical and thermal characteristics], i.e., the ability to design a repository that does not significantly alter the geologic barrier. The selected repository medium must also allow for design of disposal pits that do not require access to adjust tolerances during filling operations. Research is to be performed, especially with coupled modeling of thermal and mechanical phenomena, on the influence of waste placement modes and sequences on mechanical effects in the repository, and particularly the amount of preliminary cooling and the density of waste disposal containers. This research will make it possible to determine the corresponding physical parameters and to identify the influence of these phenomena.”

Geochemical Characteristics

“[Geochemical characteristics] play an important part in the long-term safety of a radioactive waste repository because they can have an effect on the alterability of man-made barriers, and they govern retention retention phenomena for radionuclides that may have been released. A quantitative description of the geochemical characteristics of the system is to be established to provide for an analysis of radionuclide transport conditions. Mineralogical analyses of the materials of the host formation are to be performed, and their geochemical evolution modeled as a function of temperature and irradiation. The role of clay minerals in particular will be studied.”

Minimum Depth

“The selected site must be such that the projected repository depth guarantees that the containment performance of the geologic barrier is not significantly affected by erosion (particularly after glaciation), by a seismic event, or by ‘normal’ intrusion. The surface area that could be disturbed in this manner is to be assumed to be approximately 150 to 200 meters.”

Depletion of Underground Resources

“With regard to underground resource management, the site is to be selected in a manner that avoids areas with a high value, whether known or suspected.”

Obviously, requirements for selection of the geologic medium for the repository site are not unrelated to initial site suitability characteristics. Accordingly, the FSR specifies the following:

“The location of the repository site in the geologic formation must be:

- *in a host block devoid of large faults likely to constitute preferential sectors for hydraulic flows in the case of crystalline media, with disposal modules to be built away from typical fracturing, although access structures could penetrate the latter; and*
- *in a medium devoid of large heterogeneities and at an adequate distance from surrounding aquifers in the case of sedimentary rock.”*

10.3.2 Characterization Methodology

To supplement these rather general considerations, the FSR provides the equivalent of a scope of work for the type of investigations to be conducted, and sometimes for the methods to be employed, to characterize a site in terms of the criteria identified above. The impacts of media-specific particularities on the generic workscope are specified, as in the case of hydrogeological studies.

Crystalline Site

“For deep hydrogeology, and particularly for water transport times and discharge identification, studies are to be performed on fracturing on a variety of scales (low fracturing, hectometric fracturing, large faults bordering the host block) and on all other elements necessary for modeling.”

Salt-formation Site

“For surface and lateral hydrogeology, detailed analysis of the hydrologic balance of each catchment basin is to be performed to estimate surface aquifer supply. For all aquifers, a regional hydrogeologic diagram is to be prepared showing supply areas, discontinuities, discharge areas, and interactions between aquifers as well as a hydrogeologic balance. A local hydrogeologic study is to be performed showing the geometric characteristics of the aquifers (lithostratigraphic type, morphology, continuity, etc.) and of the impermeable layers and their hydrodynamic characteristics (permeability, transmissiveness, porosity, etc.), taking into account the influence of host rock fracturing in particular and any other element necessary to quantify flows, such as local pumping. These hydrogeologic assessments are to make it possible to predict the probabilities of dissolution.”

Clay-formation Site

“Surface hydrogeology is to be described at the local level to estimate surface aquifer supply. The following elements are to be determined as precisely as possible for all formations:

- *a regional hydrogeologic diagram showing source/depletion areas and the interaction between aquifers as well as a preliminary hydrogeologic balance;*
- *a local hydrogeologic diagram showing:*
 - *the geometric characteristics of the aquifers (lithostratigraphic type morphology, continuity, etc.) and of the semipermeable and impermeable levels;*
 - *their vertical and horizontal hydrodynamic characteristics (porosity, permeability, [transmissiveness, etc.], taking into account host rock fracturing in particular and any other element necessary to quantify flows;*
 - *their geochemical characteristics, particularly salinity; and*
 - *their hydrodynamic parameters and the geometry of any vertical discontinuities which could result in interactions among different stratigraphic levels.”*

10.4 REPOSITORY DESIGN

The fundamental objective of the deep geologic waste repository is to protect members of the public and the environment now and in the future (FSR III.2.f).

Decree 92-1391 of December 30, 1992, concerning Andra requires that Andra submit a summary report to its oversight ministries no later than December 31, 2005 on the results of research, accompanied as appropriate by a repository design. The law clearly stipulates that the decision to create a repository is subject to numerous conditions. Foremost among these is the review of the various waste management research programs by the National Assessment Commission.

10.4.1 Performance Assessment

What tools will be used for performance assessment and how will Andra apply them to the development of its design concept?

Direct assessment of the effectiveness of the various barriers in a repository for Category B waste isn't possible due to the length of time required for containment. Long-term performance assessment depends on several scientific disciplines and follows an approach that is naturalistic, experimental and model-based to understand phenomena brought into play by the repository.

The naturalistic approach is quantitative and historical; it compares the various geologic situations observed to a historical and experimental understanding of the medium. In particular, this approach provides information on the past evolution of sites (climate, neotectonics) over time scales consistent with the radioactive decay periods of the radionuclides in the repository in order to predict future behavior.

The experimental approach provides access to host formation behavior at various locations so that: properties can be measured or at least assessed in actual conditions, disturbances to the host rock caused by the repository can be identified and ranked, behavior models can be validated and the repository concept can be adapted to the reference medium.

Modeling is a means of summarizing data from a variety of fields to understand the effects of thermo-hydro-mechanical and chemical coupling; it is used to perform sensitivity analyses and simulations.

All of these approaches are used simultaneously rather than sequentially, and all results are factored into the performance assessment.

As the last step in the process, FSR 111.2.f also requires

that changes in the behavior of the repository be monitored over time: *"Given the period of time involved in repository operations and the disturbances caused during that period, specialized instrumentation is necessary to monitor changes in site and repository structural parameters. Said instrumentation is to be set up as soon as possible to ensure that the repository structure and the site are monitored not just during repository operations, but before them as well. In particular, the following should be monitored:*

- *site piezometry;*
- *deformations and more generally behavior over time of the walls of the repository that are to remain open for very long periods of time (certain reconnaissance bore holes, access shafts, service galleries);*
- *seismic movements; and*
- *thermal behavior of the medium and its effects (constraints, displacements, fracturing, etc.)."*

10.4.2 Design Concept

Having presented the regulatory and legislative context in which Andra performs research on high-level and long-lived waste disposal, the repository concept and Andra's approach to the feasibility study of the repository will be explained. Andra must first:

- identify the principal functions of the repository, which must contain the radionuclides in the waste packages, i.e., minimize and retard their potential release and migration to protect the environment and members of the public now and in the future; and
- examine the potential for waste package recovery during the period of retrievability.

To meet these requirements, the repository concept includes several elements that respond to specific objectives, particularly:

- an underground facility layout that can be adapted to the conditions likely to be encountered in deep geologic formations;
- waste placement systems; and
- radionuclide containment systems including solidified waste and geologic formations with complementary artificial barriers.

The technical feasibility of these functions requires assessment to verify that it will be possible to construct, operate and close the facilities in accordance with the requirements identified earlier while responding to the

following questions:

- What constraints must be placed on the facilities due to their depth and the high temperatures generated by certain high-level wastes?
- Are there technological answers that are readily available to industry?
- Given the current limitations in knowledge and technology, what developments are necessary in the fields of mining engineering, underground handling of radioactive materials, and construction of man-made barriers?

The constraints applicable to Category C waste are different from those of B waste, which would appear to translate into specialized features for the repository. In addition to justifying the proposed technical solutions, feasibility studies are needed to identify potential requirements for additional research and development for the solutions under investigation.

10.5 UNDERGROUND RESEARCH LABORATORIES

The Waste Act designates underground research laboratories as one means of investigating the potential for retrievable or non-retrievable disposal in deep geologic formations. Andra's research objectives for these laboratories are as follows:

- perform in situ rock or fluid measurements while disturbing these materials as little as possible to understand the parameters already partially assessed during the surface reconnaissance program;
- conduct more general experiments to determine the behavior of the various rocks and fluids, taking into consideration natural phenomena and modifications caused by the construction of a potential repository as well as by the presence of waste packages;
- investigate the medium, particularly its spatial variability, to assess site suitability and the possible location of galleries and future repository excavations; and
- determine the data needed to design excavation, backfilling and closure of the disposal sites.

It should be noted that a large number of lithologic, structural, petrographic, hydrogeologic, thermomechanic and tectonic characteristics are already available at the surface, which make it possible to analyze them in a regional context and conduct a preliminary assessment of the suitability of the site to host a repository. This preliminary assessment will be expanded and supplement

ed by investigations in the underground laboratories. Surface and underground work can be conducted in parallel rather than sequentially.

The Waste Act and its implementing Decree 9340 of July 16, 1993, specify the conditions under which laboratory construction and operation will be licensed. The sheer size of the laboratories makes them true industrial projects. There will be complete openness in the methodology used, as set forth in FSR III.2.f, which identifies essential and important criteria for site characterization and specifies general requirements for site investigations in Appendix 1.

The primary purpose of the measurements and tests to be conducted on site and in the laboratory is to confirm the initial assessment of the site's qualities and drawbacks and the overall adequacy of the selected location. In addition to initial measurements and tests, phenomenological studies and tests in the underground laboratories, along with research of a more fundamental nature in conventional laboratories, will help Andra to assess the site behavior in more depth and detail that results from the disturbances to which it has been exposed during construction and disposal.

It should be noted that validation of the complex approach described above involves an experimental period that cannot be cut short, followed by interpretation of test results, which translates into a rather tight schedule.

10.6 ANDRA RESEARCH PROGRAMS

10.6.1 Research Budget and Participants

Andra has embarked on a vast research program in furtherance of its missions, as reflected in this report and in the large budget and numerous contractors reporting to Andra. The 1993 deep disposal research budget was FF 250 million francs for planning activities alone.

The size of the subcontractors varies widely; some research is so specialized that sometimes only a university laboratory or a single engineering company can respond. On the other hand, it is sometimes necessary to turn to large groups such as BRGM [French Geological Survey], CEA [Atomic Energy Commission], EDF, MDPA, Bertin, Cogema, and others. Andra controls the research objectives, of course, but may also select the laboratory within these organizations that is best suited for the work requested.



The Agency's research and development programs are scrutinized by its Scientific Council, who:

- issues, opinions and recommendations on scientific and technical objectives and on costs,
- is kept informed on progress, and

- assesses the results of these programs.

The opinions, recommendations and report of the Scientific Counsel are submitted to Andra's Board of Directors. Andra's research results for the year are set forth in its annual report on research and development, presentations by Andra and its suppliers at international